Pavement Management: Capturing Surface Treatment Effectiveness

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Abstract—**Acquiring detailed knowledge of surface treatments effectiveness is required to improve performance-based decisions for allocating resources to preserve and maintain pavements on any road network. Measurement of treatment effectiveness is a complex task that requires historical records of treatments with observations of before and after performance trends. Lack of data is often an obstacle that impedes development and incorporation of surface maintenance treatments into pavement management. This paper analyzes the effect of surface treatments on asphalt paved arterial roads for several control sections of New Brunswick. The method uses a Transition Probability Matrix to capture main effects by mapping mean trends of surface improvement and pavement structure decay. It was found that surface treatments have an immediate effect reducing the rate of loss of structural capacity. Pavements with international roughness index (IRI) smaller than 1.4 m/km did not seem to benefit from surface treatments. Those with IRI higher than 1.66 m/km gained from 6 to 8 years of additional life. Reset value for surface treatments fall between 1.18 and 1.29 m/km. This paper aims to serve to practitioners seeking to capture and incorporate effectiveness of surface treatments (i.e., crack-sealing) into Pavement Management.**

Keywords—Pavement; Management, Interventions; Effectiveness

INTRODUCTION

Pavement Management Systems (PMS) are useful tools to aid in the decision making of treatment allocation to address expected deterioration of roads (1). They rely heavily on performance models for deterioration and treatment effectiveness. Performance models must be calibrated to local conditions (2). Precise knowledge of pavement deterioration can be obtained from historical records of deterioration trends. However, typification of treatment effectiveness is often difficult because lack of records of treatment history and before-after performance (3,4). The effect of surface treatments like crack sealing, slurry seal, fog seal, micro-surfacing or thin hot-mix overlay is even more difficult to estimate because such treatments may result in extensions of lifespan plus changes on the slope of deterioration of surface condition (4,5). Changes in structural capacity (4, 5) may arise after waterproofing the surface, slowing down the rate of structural degradation having prevented water from entering the structure (6).

Selecting the most cost-effective treatment at the right time is crucial for pavement management: especially for the achievement of agency performance goals of sustaining pavements at good levels of condition (7, 8). The realization of the advantages to preserve assets instead of defer maintenance and incur in larger expenditures made agencies realize of the need to incorporate maintenance management into pavement management (9) therefore applying surface treatments to relatively good roads, however, such incorporation requires good understanding of after treatment effects on pavement performance, both on the surface and structure.

The objective of this paper is to present a method to measure surface treatment effectiveness. The analysis takes the form of before and after comparisons. A surrogate apparent age is used to develop degradation curves for pavement structural capacity. Transition probability matrices are used to capture the effect on the surface and on the structure of deploying surface treatments, measuring lifespan extension, reset value, and after treatment performance.

I. METHODOLOGY

A. Deflection Basin Parameter (DBP) – Area

Falling Weight Deflectometers (FWD) are often used to evaluate the physical properties of pavements. FWD data is primarily used to estimate pavement structural capacity. FWDs impose a load pulse to a pavement surface by dropping a large weight, simulating the load of a vehicle's wheel. Deflection sensors mounted at fixed offsets from the center of a load plate measure the deformation of the pavement in response to the load. Direct analysis of deflection data can be done by using a Deflection Basin Parameter (DBPs) as a surrogate of pavement strength (10). The Area deflection basin parameter (Area) has been used as proxy of pavement structural capacity in the absence of structural number due to the lack of information on the thickness of pavement layers (11). Equation 1 shows the Area DBP used in this paper.

Error! Reference source not found. $6(D_0 + 2D_1 + 2D_2 + 2D_3) / D_0$ (1)

Where D0, D1, D2, and D3 are FWD deflection readings at zero offset, first offset, second offset, and third offset geophones respectively. Theoretically Area can fluctuate from 36 (strong) to 11.1 (weak), however observed values for the dataset of this paper ranged from 17.7 to 32.6.

B. Modeling Deterioration of Area deflection basin parameter: an apparent age approach

Performance models were developed from cross sectional data of thousands of segments of roads and longitudinal data for 6 years (1991 to 1996). An apparent age (surrogate of condition) was correlated with pavement condition (i.e., deflection basin parameter) as suggested elsewhere (12). Road segments were divided into groups based on traffic intensity or environmental exposure. Further, four qualitative subgroups of condition were defined (i.e., good, fair, poor, very poor). Finally, segments that showed signs of deterioration for two consecutive years were rearranged in pairs (initial, final), and their average condition was calculated.

The procedure started by assuming an apparent age (AGE_1) of zero for as-built FWD of 31 (highest observed value), this is called breakpoint one (BP_1). This arbitrary assumption was based on the highest observed Area deflection basin value for the network and can be customarily adjusted for other calibrations. The first apparent age (AGE_1) to be determined was for the pair of average Area basin points for roads in 'Good' condition ($\mu_{initial}^{Good}, \mu_{final}^{Good}$). This was determined by finding the age value of the second break point (AGE_2) that achieved the objective of separating the first pair of average IRI points ($\mu_{initial}^{Good}, \mu_{final}^{Good}$) by a distance of 1 year, which is the time elapsed between successive condition surveys. The apparent age (AGE_3) for the third breakpoint (BP_3) used the just established apparent age of the second breakpoint (AGE_2) to find the value of the corresponding age of the third break-point (AGE_3) that achieves a distance of 1 year between the second pair of average fair IRI points ($\mu_{2004}^{Fair}, \mu_{2006}^{Fair}$). This procedure continues in this fashion using the average values of initial and final Area basin for Poor and Very Poor pairs of average pavement condition until all apparent ages have been established. Equation 2 was used for finding the apparent age of each break point.

$$\frac{BP_n - \mu_{final}}{\left(\dfrac{BP_n - BP_{n+1}}{AGE_{n+1} - AGE_n}\right)} - \frac{BP_n - \mu_{initial}}{\left(\dfrac{BP_n - BP_{n+1}}{AGE_{n+1} - AGE_n}\right)} = 1 \qquad (2)$$

Where, BPn represents the break point (i.e., Area basin) corresponding to apparent age n; AGEn= apparent age n; and initial or final = the mean condition (Area basin) of the group at any initial or final year. Apparent ages for the break points of the traffic intensity groups were used as a basis to assign apparent ages for different groups. A performance model was built by plotting pairs of apparent ages and breakpoints.

A. Transition Probability Matrix

Transition Probability Matrices are a widely accepted technique for generating stochastic performance models that reflect uncertainty of future conditions (13, 14, 15). The matrix represents the probability distribution of future periods of time. Equation 3 illustrates a TPM. Two cases are possible: (a) a mixed (improvement – deterioration) TPM1 with values all across its cells, or (b) a pure deterioration (or improvement) TPM2 composed of zeros below (above) the main diagonal and deterioration (improvement) values above it (below it). In a mixed TPM the values above the main diagonal stand for deterioration while the values below it accounts for treatment improvement.

Stages: 1 2 3 n

$$TPM_1 = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & & & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{bmatrix}$$

$$
\mathrm{TPM}_2 = \begin{bmatrix} p_{11} & p_{12} & p_{13} & \cdots & p_{1n} \\ 0 & p_{22} & p_{23} & \cdots & p_{2n} \\ 0 & 0 & p_{33} & \cdots & p_{3n} \\ \vdots & \vdots & \vdots & & \vdots \\ 0 & 0 & 0 & \cdots & 1 \end{bmatrix} \qquad (3)
$$

Each element of the TPM reflects a specific probability which depends on its location. The nomenclature pij represents the probability that an element initially in the condition state "i" moves to the state "j" when a one time step transition happens. Each row of the TPM matrix sums up to 100% of probable future states. As one move away from the main diagonal, a higher deterioration or improvement is observed. Many studies have attempted to estimate TPMs (16, 17, 18). However, the success of this procedure is directly dependent on the existence of quality historical condition data, the precise knowledge of local conditions and the causal factors which account for the deterioration in order to divide the information into families of pavements.

A. Steps for capturing treatment effectiveness

1) Gather performance data,

a) At least one indicator of surface condition and one of structural capacity

b) Obtain record of treatments

2) Get subsets

a) Pavements treated by each specific treatment type

b) With records of performance before and after treatment

3) Divide segments into families of pavements

4) Develop deterioration curves per pavement family

a) Use time series analysis, if sufficient data

b) Use apparent age approach, if insufficient time series data

5) Generate a TPM per group and condition indicator

a) Synchronize each cell movement to coincide with 1 year of deterioration

b) Use deterioration curves developed in step 4

6) Measure treatment effectiveness using the TPM

a) Service life extension (reset value)

b) Changes in slopes

c) After treatment performance

Ideally the indicator of surface condition (step 1a) must be the one used to trigger specific treatments; i.e., cracking for crack sealing, rutting and cracking for micro-surfacing, etcetera, NBDOT have a protocol establishing such treatment criteria and operational windows (19). The TPM produced by the previous procedure is expected to be used in combination with decision rule sets as those suggested elsewhere (9) to allocate maintenance and rehabilitation treatments for pavement management.

II. Case Study: Segments from Routes 1 and 8 of New Brunswick

A database with surface condition (IRI) and pavement structural capacity (Deflection Area basin parameter) previously assembled (11) was used in this paper. The data contained six years of observations in the form of international roughness index (IRI) and Area deflection basin parameter (AREA). A subset of data points was selected from segments receiving surface treatments from 1991 to 1996. This resulted in 45 segments of 161m (1/10 of a mile) length from two sites: Group 1: 3540 meters of control section 18 of route 8 and, Group 2: 4184 meters from control section 8 of route 1, both receiving surface treatments during 1991 or 1995 correspondingly. All sections came from asphalt-paved arterial roads. However, group 1 had a moisture index of 60 and group 2 of 80, annual freeze thaw day-cycles was similar: 16.81 and 14.29 days per year, correspondingly. Table 1 shows observed condition and traffic loading per segment, as seen, there was missing data from FWD readings not collected for some of the segments.

TABLE I. SECTIONS USED IN THE ANALYSIS

	International Roughness Index (m/km)						*Area Basin - FWD*						*ESALs*	
YEAR	1991	1992	1993	1994	1995	1996	1991	1992	1993	1994	1995	1996	Before	After
1991	2.77	1.97	2.13	2.23	1.80	1.53							404732	204034
1991	1.84	1.36	1.61	1.51	1.42	1.70	22.03	21.69	21.18	26.59	23.86	21.82	404732	204034
1991	1.77	1.43	1.59	1.57	1.42	1.70	24.16	24.59	23.91	28.84	25.46	25.07	404732	204034
1991	1.44	1.49	1.50	1.67	1.19	1.57							404732	204034

1991	1.52	1.41	1.50	1.53	1.37	1.77	22.63	22.74	22.44	25.08	23.22	22.13	404732	204034
1991	1.38	1.28	1.32	1.35	1.32	1.94	19.96	19.81	18.27	19.66	19.60	19.38	404732	204034
1991	1.75	1.70	1.77	1.68	1.24	1.75	22.65	22.71	21.72	23.14	20.35	20.09	404732	204034
1991	1.98	1.88	2.01	1.97	1.43	1.92	19.43	18.36	17.68	29.07	19.50	19.29	404732	204034
1991	1.58	1.49	1.56	1.45	1.72	2.21							404732	204034
1991	1.54	1.53	1.55	1.54	1.57	2.02	22.83	23.74	21.42	24.57	23.10	21.83	404732	204034
1991	1.63	1.57	1.55	1.53	1.21	1.84	20.48	18.69	18.61	23.17	20.26	19.65	404732	204034
1991	2.02	1.99	2.11	2.07	1.20	1.90	25.61	25.31	23.52	31.70	25.47	24.00	404732	204034
1991	1.91	1.82	1.98	1.95	1.38	1.72	23.08	23.82	21.68	25.28	22.88	21.93	404732	204034
1991	1.75	1.57	1.66	1.93	1.43	1.75							404732	204034
1991	2.05	1.90	2.05	2.12	1.41	1.98	22.35	22.10	20.81	25.17	23.36	22.24	404732	204034
1991	2.27	2.13	2.23	2.22	1.35	1.80	23.12	25.87	22.84	25.23	24.66	23.81	404732	204034
1991	1.47	1.39	1.38	1.40	1.35	1.75	19.21	20.44	18.31	28.18	20.11	20.00	404732	204034
1991	1.53	1.52	1.52	1.54	1.43	2.09	20.93	21.41	19.76	18.45	18.77	18.18	404732	204034
1991	2.76	2.84	3.09	3.44	1.46	1.91							404732	204034
1991	2.06	2.15	2.26	2.09	1.61	1.93	22.69	19.86	19.62	21.54	21.94	20.94	404732	204034
1991	1.61	1.44	1.92	1.60	1.57	1.67	26.55	29.56	25.37	24.62	19.31	18.41	404732	204034
1995	2.32	2.34	2.32	2.36	1.52	2.06	21.83	22.42	21.20	23.33	21.24	19.92	556877	578372
1995	1.83	2.24	1.86	1.81	1.47	1.83	22.95	23.57	22.20	22.77	21.75	21.09	556877	578372
1995	1.21	1.15	1.17	1.16	1.39	1.72	20.48	19.25	19.07	22.62	22.63	20.55	556877	578372
1995	1.13	1.03	1.01	1.00	1.60	1.98	23.19	24.55	23.06	26.95	20.01	18.91	556877	578372
1995	0.99	1.08	1.15	1.04	1.22	1.34	22.78	21.78	25.00	24.06	23.16	24.30	556877	578372
1995	0.87	1.08	0.97	0.89	1.09	1.25	23.36	22.27	30.46	25.10	23.72	24.43	556877	578372
1995	1.12	1.13	1.06	1.05	1.14	1.44	25.58	24.73	25.70	24.23	23.06	23.64	556877	578372
1995	1.34	1.32	1.35	1.49	1.62	1.85	22.85	22.48	30.82	24.10	23.27	24.46	556877	578372
1995	1.20	1.22	1.43	1.39	1.48	1.97							556877	578372
1995	0.98	1.10	1.08	1.14	1.24	1.86	24.88	24.30	32.63	26.97	24.63	25.03	556877	578372
1995	0.81	0.86	1.07	0.88	1.00	1.63	23.99	23.20	23.54	25.91	23.42	24.24	556877	578372
1995	1.49	1.61	1.54	1.48	1.63	2.12	26.46	26.40	28.07	27.63	27.17	28.21	556877	578372
1995	0.90	1.60	0.88	1.04	1.18	1.68	23.98	23.06	29.63	26.76	24.74	24.82	556877	578372
1995	1.01	1.13	1.00	1.18	1.47	1.99							556877	578372
1995	0.98	1.01	1.22	1.03	1.24	1.77	24.97	24.13	23.66	26.86	22.66	23.34	556877	578372
1995	1.04	1.03	0.92	1.04	1.24	1.82	24.46	23.70	28.58	26.51	26.08	27.40	556877	578372
1995	0.97	1.15	1.10	1.44	1.59	2.19	25.77	25.65	27.11	25.44	24.86	26.30	556877	578372
1995	1.10	1.19	1.13	1.25	1.38	2.14	22.81	22.73	26.99	25.59	24.10	24.79	556877	578372
1995	1.43	1.60	1.53	1.66	1.74	2.30	26.26	25.72	26.28	27.66	26.16	26.50	556877	578372
1995	1.39	1.45	1.43	1.51	1.59	1.99	24.70	24.48	30.52	24.54	24.19	25.64	556877	578372
1995	1.53	1.63	1.84	1.62	1.79	2.05	25.04	23.92	25.88	25.17	23.80	25.22	556877	578372
1995	1.48	1.46	1.62	1.50	1.66	2.13	23.45	23.41	29.00	25.10	24.77	25.52	556877	578372
1995	1.31	1.43	1.44	1.66	1.74	2.11							556877	578372
1995	1.68	1.82	1.98	2.32	2.38	2.53	25.53	25.10	30.30	26.35	24.28	25.46	556877	578372

1995	1.48	1.60	1.64	1.75	1.94	2.58	22.94	22.82	31.87	24.86	23.98	24.56	556877	578372

Note: ESALs = equivalent single axle loads (standard axle of 80,000kN or 18,000lbs)

III. Analysis of Results

A. *Exploratory analysis*

Box-plots of IRI for before, after and when the treatment was applied, resulted in a clear indication that for group 2 (treated on 1995) the variability of observed roughness diminished after receiving a surface treatment, even though IRI increased from the year before (Figure 1). Before treatment data for group 1 (receiving a treatment during 1991) was missing, only after treatment could be observed, noticing a negligible increment on IRI (Figure 1). This drastic difference can be explained by the fact that traffic loading (ESALs) on route 8 control section 18 (group 1) dropped from the year of application (of surface treatment) to the following year from 404272 to 204034 ESALs (Table 1).

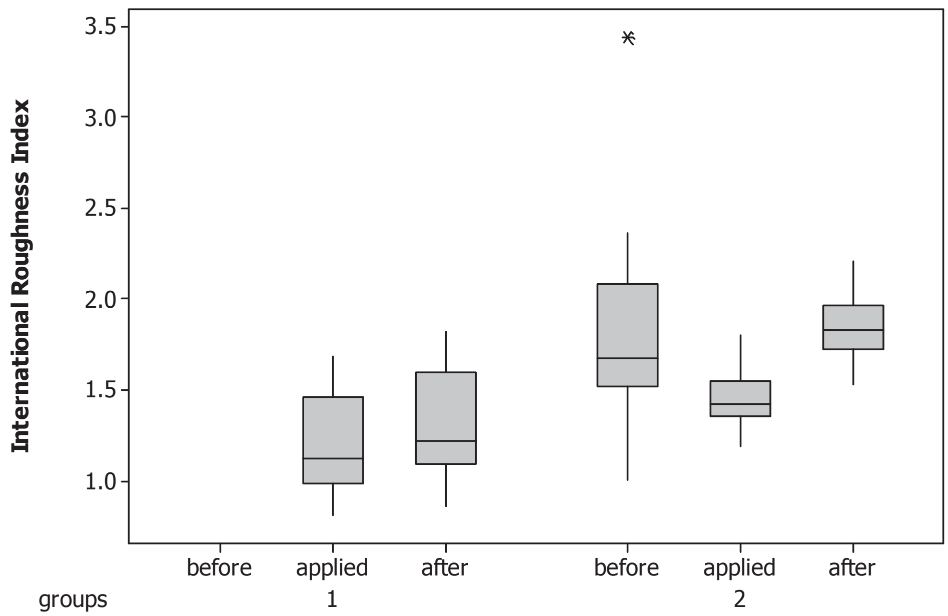

Fig. 1. Box plot of before, after and at year of treatment application, groups 1 and 2

A line plot of individual values of before and after roughness (IRI) confirms that for group 2, the overall variability dropped (comparing before and applied lines), but in addition, that those segments with poorer condition benefited the most (Figure 2). However, such rejuvenation seems to last somewhere about two years, by simply contrasting the line trends of the year of application with the one before and after. For group 1 very close trend can be observed between the year of application and the one immediately following. Even though the after-line shows some signs of wearing, it is by far much less than that showed by group 2, because of the drop (-49.6%) in traffic loading on group 1 as compared to a 3.86% increase for group 2.

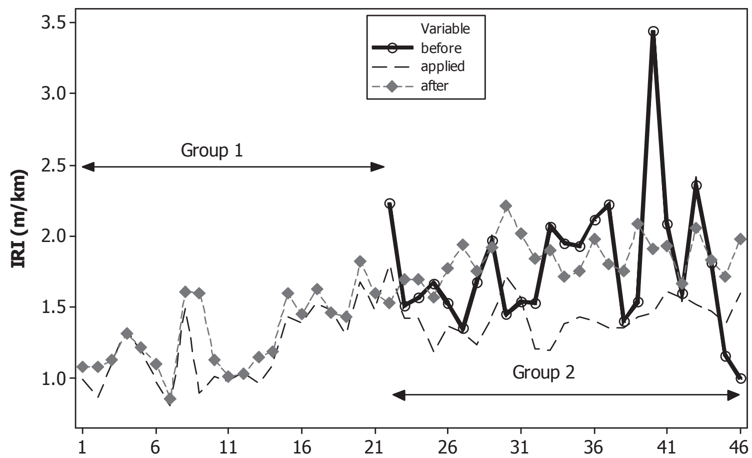

Fig. 2. Profile of surface condition (IRI) before and after a surface treatment

A box plot of Area basin parameter for group 2 showed that pavement structural deterioration slowed down after receiving a surface treatment (Figure 3), possibly because of waterproofing from sealing surface cracks.

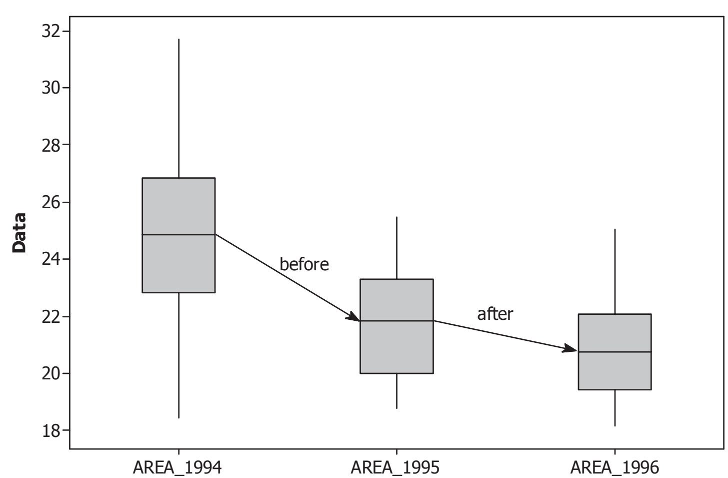

Fig. 3. Boxplot of Area deflection basin parameter (pavement strength), before and after

A similar line trend for group 2 confirmed that rate of deterioration on pavement structure slowed down for the majority of segments (Figure 4). It can also be observed how closely the year-applied and year-after lines are in contrast with the significant drop from the year-before line, for both groups, demonstrating that the application of a surface treatment seems to have an immediate effect of slowing down pavement structural degradation.

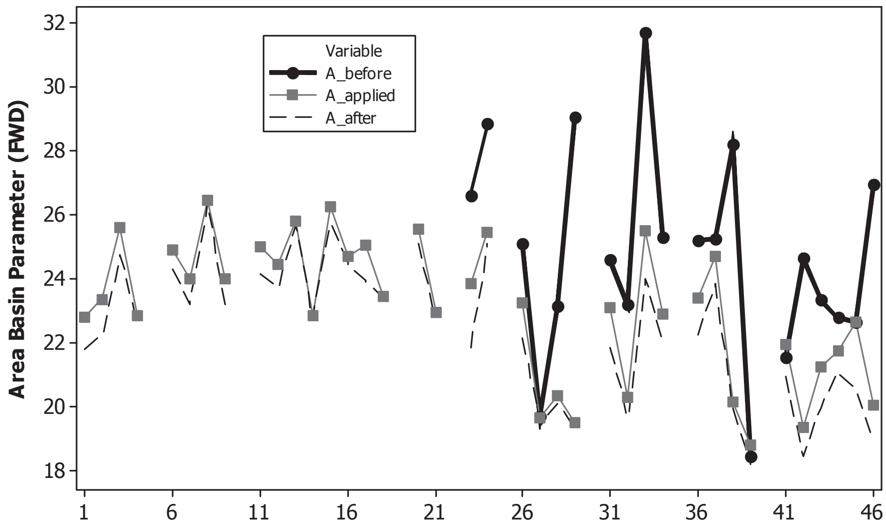

Fig. 4. Profile of structure condition (Area deflection basin) before and after a surface treatment

B. Capturing treatment effectiveness

A Markov chain was used to capture before and after treatment effectiveness for the dataset. The main idea was to observe the change of IRI for a number of segments and to express such a change on a probability matrix, in which the distance from the main diagonal represents the extension on service life. Therefore, synchronizing the values on the matrix with annual deterioration rates such that the distance between two cells corresponded to a fixed number of years (preferably one or two).

According to 19 roughness progression of AC arterial roads in New Brunswick follows an exponential relationship (Equation 4). Therefore an apparent age related to condition was obtained from Equation 1 starting at IRI = 1 m/km (for age = zero) and progressing to age 20. Eleven clusters ranging from 1 m/km to 2.5 m/km were defined using previously obtained ages and corresponding IRI as threshold values. A count of segments moving across clusters was used to capture treatment effectiveness in a transition probability matrix.

$$y = e^{0.0424x} \tag{4}$$

Each cell movement corresponded to two years of apparent age. Three segments were eliminated from the original database as they showed decay. Main diagonal corresponded to the likelihood of a segment receiving a treatment and gaining less than two years in lifespan extension. As observed, pavements in good (less than 1.4 m/km IRI) condition did not benefited from surface treatments. Segments with IRI values above 1.66 and receiving a surface treatment seem to gain between 6 and 10 years of additional life. Pavement with IRI values between 1.4 and 1.53 seem to only gain two years of lifespan extension (Table 2). IRI reset value after receiving a surface treatment lies between 1.18 and 1.29 m/km.

TABLE II. TRANSITION PROBABILITY MATRIX OF SURFACE TREATMENT EFFECTIVENESS

IRI	Age	1.00 - 1.09	1.09 - 1.18	1.18 - 1.29	1.29 - 1.4	1.4 - 1.53	1.53 - 1.66	1.66 - 1.81	1.81 - 1.97	1.97 - 2.15	2.15 - 2.33	2.33 - 2.54
1.00-1.09	**0**	**0**	0	0	0	0	0	0	0	0	0	0
1.09-1.18	**2**	0	**0**	0	0	0	0	0	0	0	0	0
1.18-1.29	**4**	0	0	**0**	0	0	0	0	0	0	0	0
1.29-1.4	**6**	0	0	0	**100%**	0	0	0	0	0	0	0
1.4-1.53	**8**	0	0	0	100%	**0**	0	0	0	0	0	0
1.53-1.66	**10**	0	0	17%	17%	33%	**33%**	0	0	0	0	0
1.66-1.81	**12**	0	0	100%	0	0	0	**0**	0	0	0	0

1.81-1.97	**14**	0	0	0	**33%**	**67%**	0	0	**0**	0	0	0
1.97-2.15	**16**	0	0	25%	0	50%	25%	0	0	**0**	0	0
2.15-2.33	**18**	0	0	0	50%	0	0	50%	0	0	**0**	0
2.33-2.54	**20**	0	0	0	0	100%	0	0	0	0	0	**0**

Figure 5 illustrates effectiveness for those segments with 1.81 < IRI < 1.97 receiving a surface treatment, as seen on Table 2, 67% of such segments will gain a lifespan extension of 6 years while 33% will gain up to 8 years.

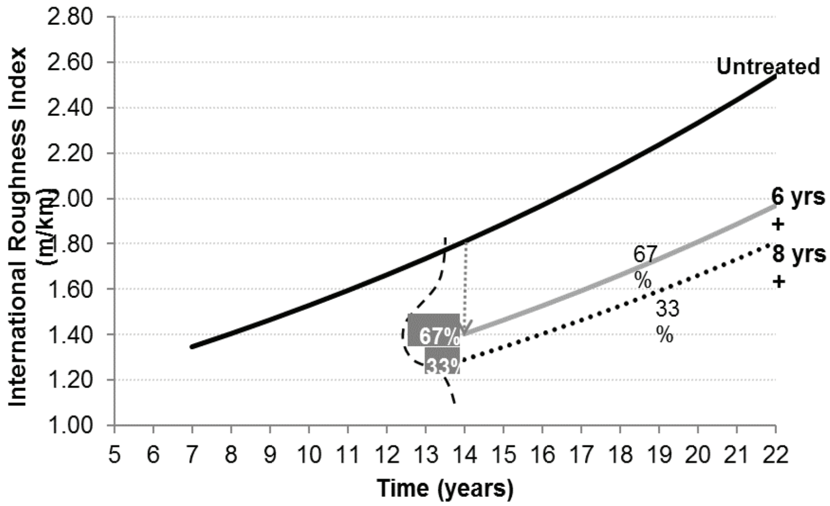

Fig. 5. Sample lifespan extension for treated segments at 1.81<IRI<1.97

Deterioration curves for Area deflection basin parameter were used to synchronize pavement structure capacity with apparent age. Traffic intensity did not seem to affect the rate of deterioration of pavement structure. A best fit curve based on apparent age approach was used to estimate the rate of deterioration (Equation 5).

$$y = -0.0141x^3 + 0.2767x^2 - 2.7998x + 28.477 \quad (5)$$

A similar transition probability matrix was developed for the before (1994 to 1995) and after trend (1995 to 1996); the idea was to measure differences in deterioration rate in terms of age (years). Tables 3 and 4 show such TPM. Decay of pavement structural capacity before the application of a surface treatment is much faster than after having received a surface treatment (Tables 3 and 4). The before trends indicate a majority of segments decaying between 2 and 4 apparent ages as measured by the deterioration model (Figure 3). Decay rates slowed to at about 1 year for all of the segments (Table 4).

TABLE III. AREA DEFLECTION BASIN – PAVEMENT STRUCTURE DETERIORATION: BEFORE SURFACE TREATMENT

Age	AREA	28.48-32.6	25.94 - 28.47	23.87 - 25.93	22.19 - 23.86	20.80 - 22.18	19.64 - 20.79	18.60 - 19.63	17.61 - 18.59
0	28.48-32.6	**0**	**0**	**67%**	**0**	**0**	**0**	**33%**	**0**
1	25.94 - 28.47	**0**	**0**	**0**	**33%**	**0**	**67%**	**0**	**0**
2	23.87 - 25.93	**0**	**0**	**0**	**83%**	**0**	**0**	**17%**	**0**
3	22.19 - 23.86	**0**	**0**	**0**	**20%**	**40%**	**40%**	**0**	**0**
4	20.80 - 22.18	**0**	**0**	**0**	**0**	**100%**	**0**	**0**	**0**
5	19.64 - 20.79	**0**	**0**	**0**	**0**	**0**	**0**	**100%**	**0**
6	18.60 - 19.63	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
7	17.61 -18.59	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

TABLE IV. AREA DEFLECTION BASIN – PAVEMENT STRUCTURE DETERIORATION: AFTER SURFACE TREATMENT

Age	AREA	28.48-32.6	25.94 - 28.47	23.87 - 25.93	22.19 - 23.86	20.80 - 22.18	19.64 - 20.79	18.60 - 19.63	17.61 - 18.59
0	28.48-32.6	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1	25.94 - 28.47	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2	23.87 - 25.93	**0**	**0**	**67%**	**33%**	**0**	**0**	**0**	**0**
3	22.19 - 23.86	**0**	**0**	**0**	**17%**	**67%**	**17%**	**0**	**0**
4	20.80 - 22.18	**0**	**0**	**0**	**0**	**67%**	**33%**	**0**	**0**
5	19.64 - 20.79	**0**	**0**	**0**	**0**	**0**	**75%**	**25%**	**0**
6	18.60 - 19.63	**0**	**0**	**0**	**0**	**0**	**0**	**50%**	**50%**
7	17.61 -18.59	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Figure 6 shows original deterioration curve and detailed trends for selected segments. A reduction on the rate of decay of structural capacity can be observed. Unfortunately, all available segments were treated after 2 years of receiving the surface treatment, impeding to observe longer after-treatment trends as those reported by other researches (3).

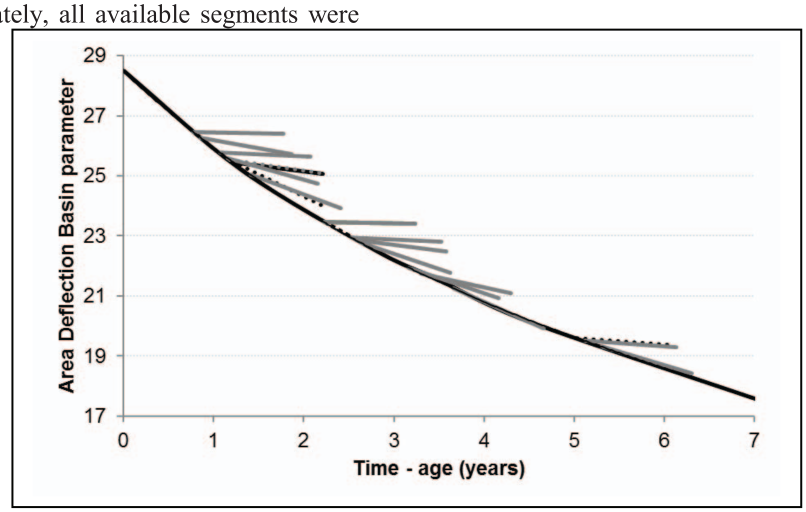

Fig. 6. Observed deterioration trends for structural capacity after surface treatment

IV. CONCLUSIONS

Exploratory analysis initially showed an ability of surface treatments to extend the service life of a pavement, the extent of such rejuvenation depended on the surface condition before the treatment. A detailed analysis using a transition probability matrix to capture treatment effectiveness revealed that pavements with IRI < 1.4 m/km did not benefit from surface treatments. Segments with IRI > 1.66 gained between 6 to 10 years of additional life. Pavements with IRI values between 1.4 and 1.65 seem to gain up to two years of lifespan extension. Reset value for surface treatments fall between 1.18 and 1.29 m/km.

For the case study, pavement structure deterioration seems to slow down after the application of a surface treatment. Several strong pavements (presumably cracked) were deteriorating fast before the application of the surface treatment. All such pavements reduced their rate of loss of structural capacity possibly indicating the benefits of waterproofing the surface.

Practitioners could capture and incorporate effectiveness of surface treatments (i.e., crack-sealing) using a TPM as herein suggested with sufficient data points to accurately map mean trends of surface improvement.

It should be acknowledged that the results herein presented are based in few pavement sections and that more data is required for practical applications. The initial findings of this paper aim to illustrate a procedure to capture treatment effectiveness on pavements.

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